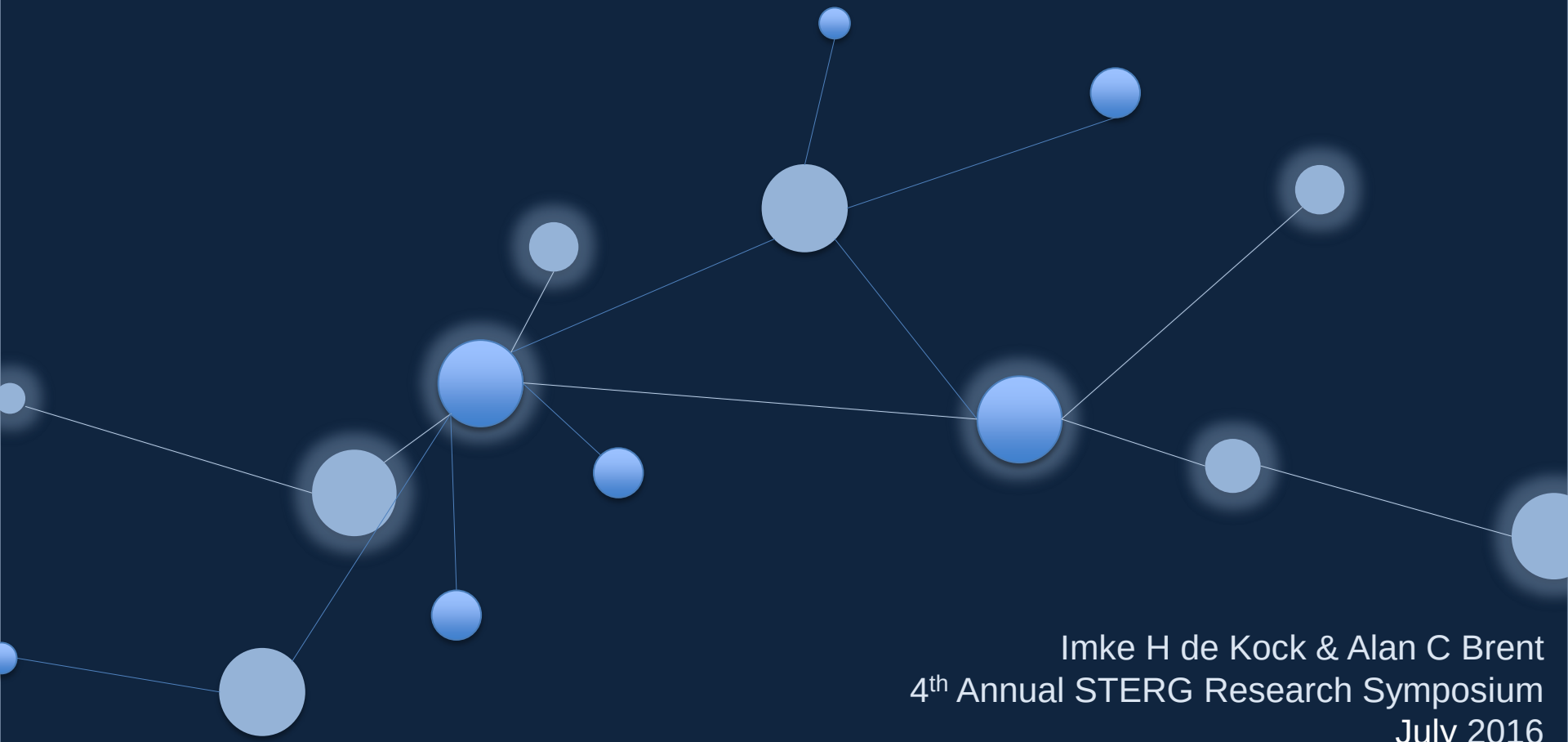
DEFINING NEXUS TECHNOLOGY: THE INTRODUCTION OF A CONCEPTUAL MODEL



Imke H de Kock & Alan C Brent

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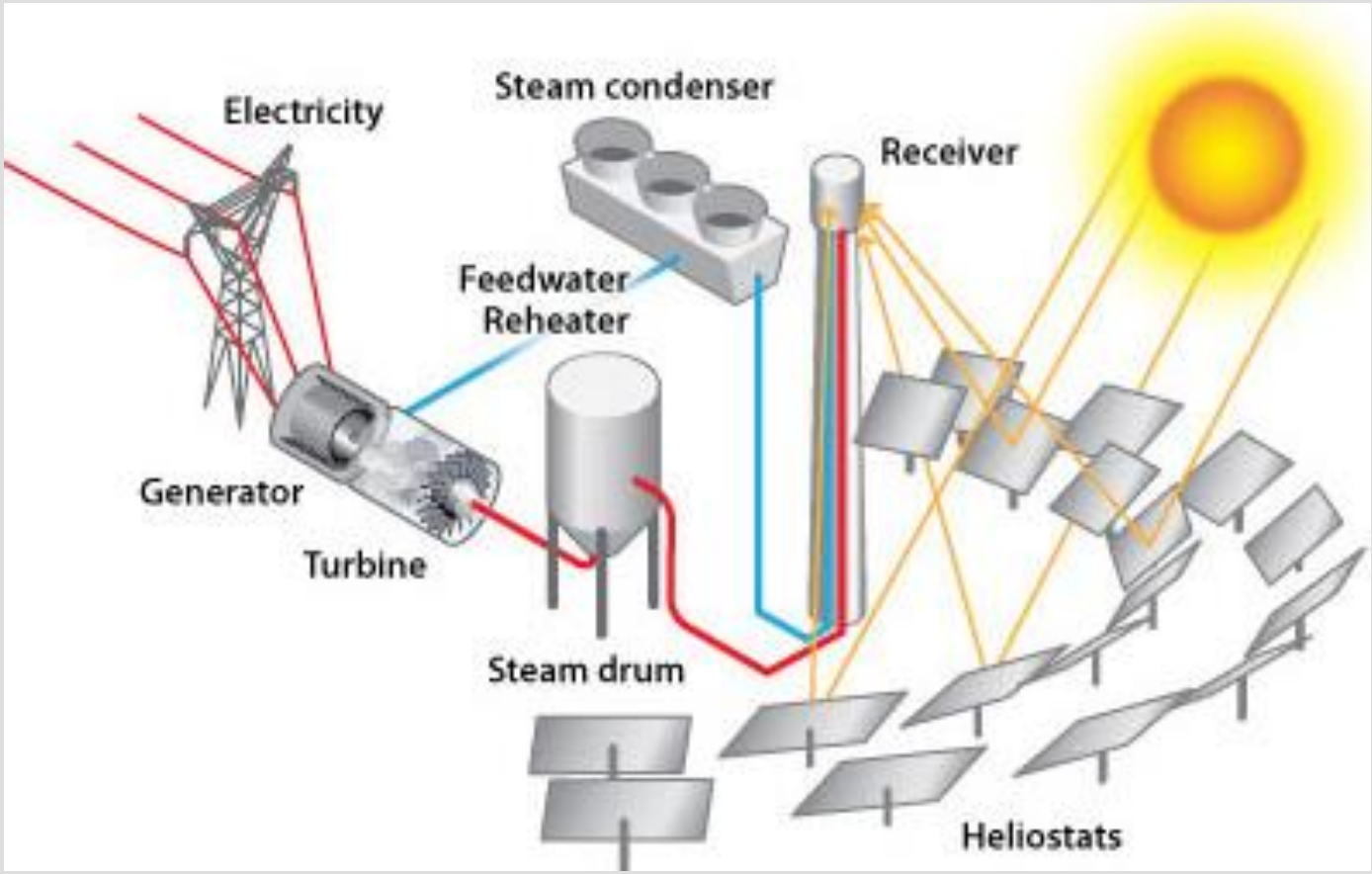
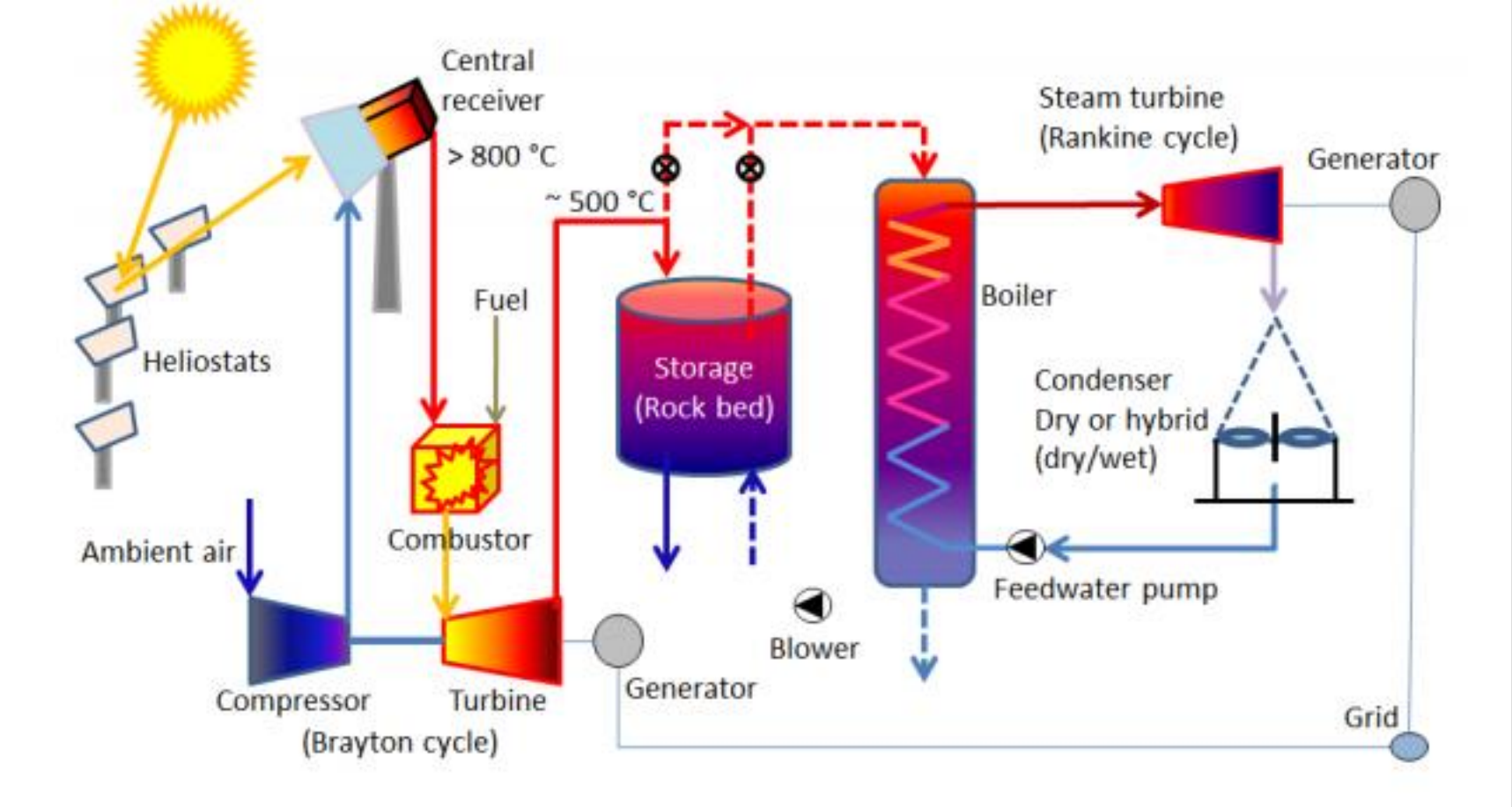
WHERE DID IT ALL START?

CONCENTRATED SOLAR POWER



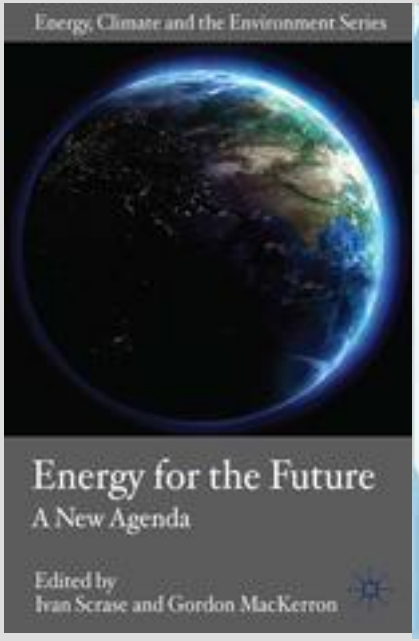
WHERE DID IT ALL START?

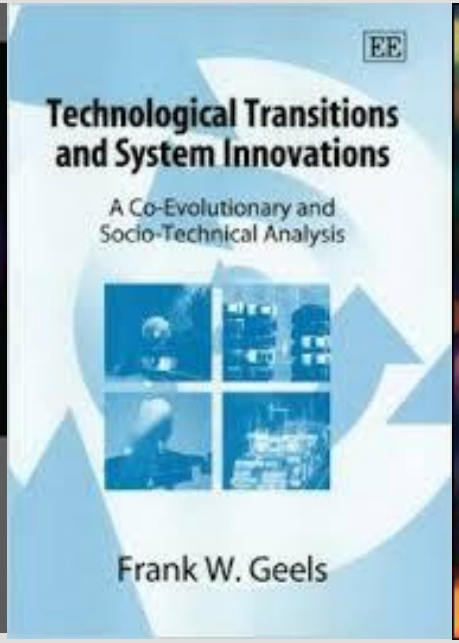
SUNSPOT

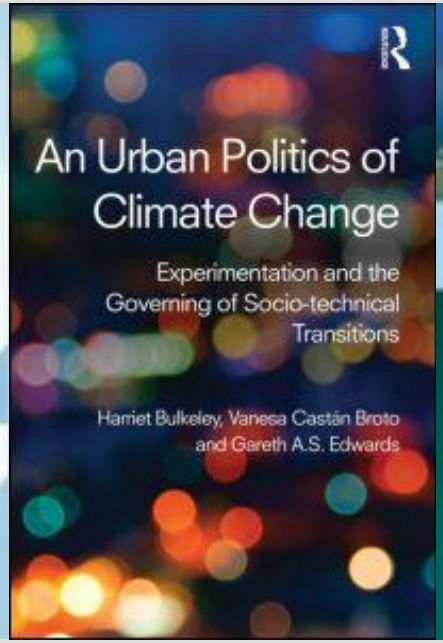


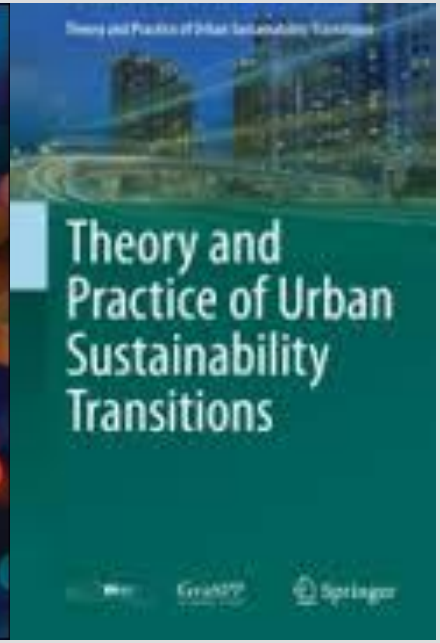
WHERE DID IT ALL START?

…AND SOCIO-TECHNICAL TRANSITIONS / SUSTAINABILITY TRANSITIONS









BACKGROUND

LARGER RESEARCH PROJECT

The management of the introduction and diffusion of nexus technologies towards large-scale far-reaching socio-technical change.

- *A vast number of technologies have been developed that aims to fulfil the promise of sustainable futures.*
- *Technological innovations that are available, as well as those being developed, are becoming increasingly sophisticated and complex.*
- *'Green' or 'sustainability' technologies emerged that* ***hold structural characteristics that are new, or different****.*
- *Referred to as* ***'nexus technologies'.***

PROBLEM STATEMENT

LARGER RESEARCH PROJECT

Understanding large-scale transitions to new technological systems, and subsequently a transition to a new socio-technical system requires ***analytical frameworks that encompass multiple approaches in ways that addresses interactions between technology and societal aspects****. From a theoretical and methodological perspective, there is then scope to develop an approach to understand the complex interactions in and between* ***nexus technologies and their possible role in socio-technical transitions****.*

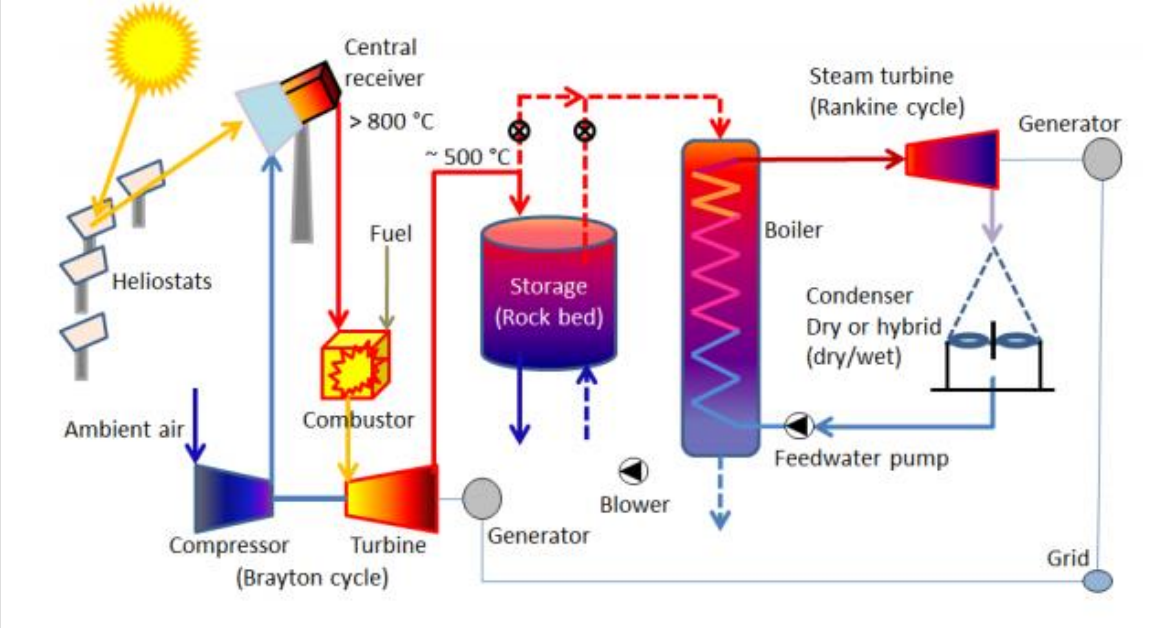
THIS RESEARCH INQUIRY

A deeper understanding of nexus technology and its defining characteristics is required to grasp the challenges associated with a nexus technology when the design, development, implementation, management, innovation and related research issues of such technologies are considered*. The primary aim of defining a nexus technology is to highlight the (unique) characteristics of this type of technology, in order to, from here, further the research and body of knowledge concerned with nexus technologies.*

OBJECTIVE

DEVELOP A DEFINITION AND CONCEPTUAL MODEL THAT WILL EFFECTIVELY:

- Describe the **structure and fit** of nexus technology;
- Define nexus technology in terms of its **complexity and configuration**;
- Describe the **level and unit of analysis** required for nexus technology;
- Describe the **function of nexus technology** as well as the technologies that form part of nexus technology; and
- Describe the **interaction** between the technologies in nexus technology.



BASIC FEATURES OF A TECHNOLOGICAL ENTITY

Characteristic	Question
Function	What does the entity do?
Principle of operation	How does it do it?
Performance	How well does it do it?
Structure	How is the entity composed?
Fit	What is the hierarchial position?
Material	What is the entity made of?
Size	How large is the entity?

(Van Wyk 2002)

CHARACTERISTICS SUNSPUT / CSP (A NEXUS TECHNOLOGY)

SUNSPOT / CSP is technology that is made up of a **number of different, individual technologies**, some of which are, or were, originally being developed without the specific nexus technology in mind. A 'nexus technology' is thus a technology that combines technologies that:

- Could possibly also serve as a **stand-alone technology with a similar or different objective or function** than the function that it fulfils within the specific nexus technology;
- All have their **own developmental paths**, separate from that of the nexus technology, as a technology in itself;
- Were **possibly unrelated technologies**, and thus also have networks that might have been previously unrelated, that are now joined within the framework of a nexus technology;
- Each technology within the nexus technology is **uniquely identifiable** (ito function);
- Possibly utilise different or separate supplier networks;
- Are possibly from **different knowledge fields**;
- Is a combination of 'off-the-shelf' technologies, and/or technologies designed specifically for the nexus technology;
- Developed using a **large number of underlying technologies**; and
- Incorporates a large number of suppliers, thus a **large number of value chains**.

A nexus technology thus consists of a set of individually developed technologies, each on their own developmental curve, with varying technology maturity levels and learning rates, configured together to form a nexus technology.

DEFINITIONS OF TECHNOLOGY

Technology Complex (Fleck & Howells, 2001)

Technical ← → Social

Author	Purpose or function (Physical science)	Material	Energy source	Artefact/hardware	Topology / layout	Procedures / software (programs, software)	Knowledge/skills/qualified people	Work organisation	Management techniques	Organisational structure	Cost / Capital	Industry structure (suppliers, users, promoters)	Location	Social/legal relations	Culture	Natural Environment*
Pacey (1983)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Zeleny (1986)	■	■	■	■	■	■	■	■	■							
Hughes (1987)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Roberts & Grabowski (1996)	■	■	■	■	■	■	■	■	■	■	■	■				
Khalil (2000)*	■	■	■	■	■	■	■	■	■	■	■	■				
Burgelma et al. (2001)	■	■	■	■	■	■	■	■	■	■	■	■				
Fleck & Howells (2001)	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
De Wet (2001)	■	■	■	■	■	■	■	■	■	■	■	■				
Grübler (2003)	■	■	■	■	■	■	■	■	■	■	■					
Haines & Sharif (2006)	■	■	■	■	■	■	■	■	■	■						
Sandeen & Hillman (2011)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Musango & Brent (2011)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

*The technology complex (Fleck & Howells 2001) did not include the natural environment)

INTERACTION AMONG TECHNOLOGY

SIX MODES OF INTERACTION BETWEEN TECHNOLOGY

Mode of Interaction	Description
Competition	Technologies compete with each other for markets and resources. Competition could be not only competition for markets, but also competition for resources. Inhibition of technologies when a short supply of resources of market exists.
Symbiosis	Interaction between technologies are favourable to all technologies involved in the concerned interaction. Complemetary products of technologies are mutually dependent in an application.
Neutralism	Neutralism is the event when occurs technologies deliver different services and use different resources, or when a common resource is a non-exclusive good. Thus technologies does not affect each other.
Parasitism (and predation)	Parasitism occurs when an emerging technology enters the market space that was developed by an established technology, or when an emerging technology makes use of the upstream supply chains that were developed by the established technology. Parasitism thus occurs when an emerging technology benefits from the existence of the established technology, while the established technology is inhibited.
Amensalism	Amensalism is the situation where an emerging technology is inhibited (structurally locked out). In this situation the emerging technology does not fit into the environment / system created or developed around an established technology. In this case, an emerging technology is inhibited, while the established technology is unaffected.
Commensalism	When one technology benefits from a resource that is developed by another technology, but the technology that developed the resource is not affected, we have a situation of commensalism.

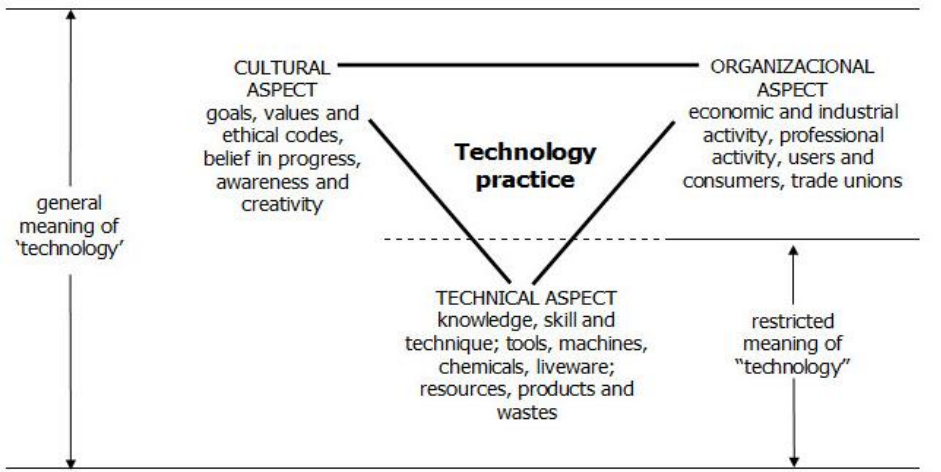
(Sandén & Hillman 2011)

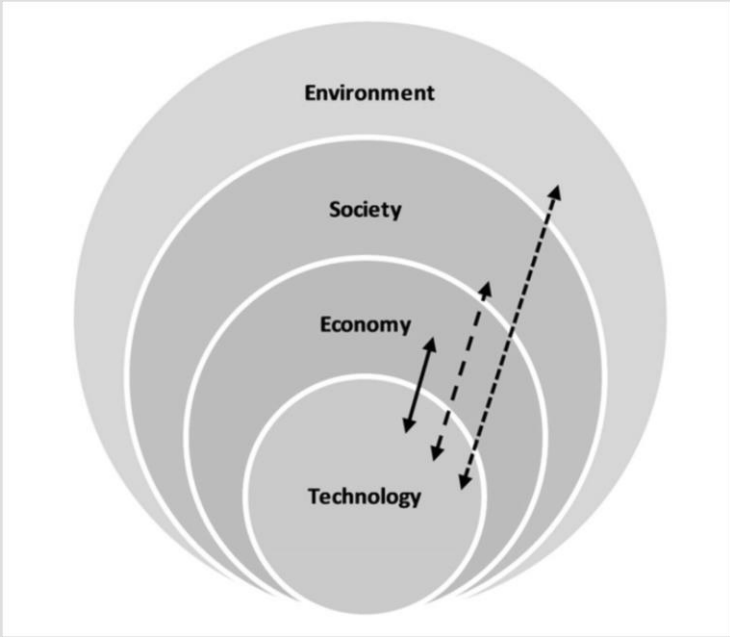
TECHNOLOGY TYPOLOGIES

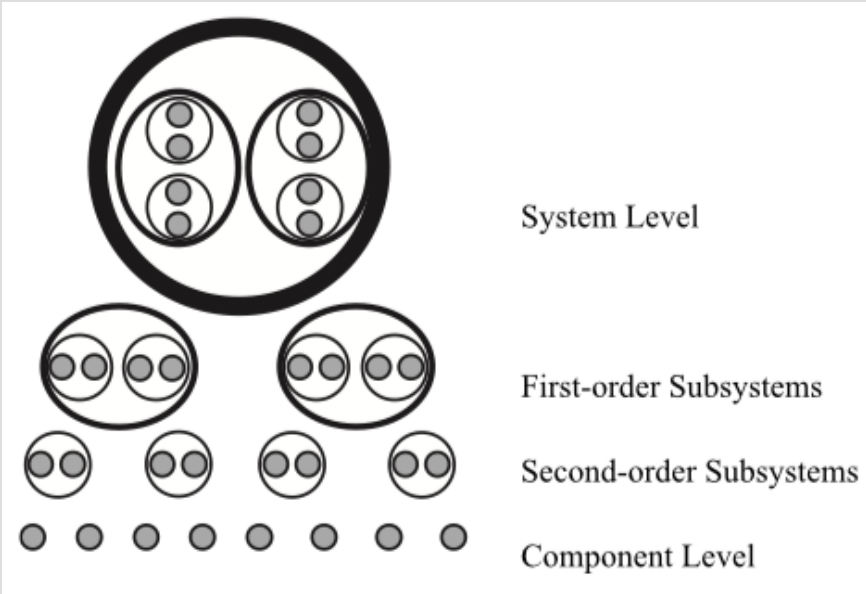
TYPOLOGIES DESCRIBING GROUPS OF TECHNOLOGIES

	Description		Structure	Example
Complex technologies (Rycroft & Kash 2002, Rycroft & Kash 1998))	Complex technologies cannot be understood in detail by an individual expert, and cannot be precisely communicated among experts across time and distance.		Numerous interacting components, produced and supplier by a range of producers and suppliers.	Aircrafts, automobiles, computers, telecommunications equipment, and the internet.
Technological systems (Bijker et al. 1987, Alkemade 2009, Aunger 2010)	Hughes (1987) states that "Technological systems contain messy, complex, problem-solving components. They are both socially constructed and society shaping", and states that technological systems comprise of four components, namely: physical artefacts, organisations, legislative artefacts and natural resources, thus the environment.		Technological systems consists of, and contains, several interdependent subsystems that function in a coherent manner. The specific combination of subsystems, and the interdependencies between subsystems, render the performance of the overall system. Technological systems have an aggregate-level functionality, as well as each component having a specific function.	World wide web, electrical power systems, telecommunication systems, transportation systems.
Complex product systems (CoPS) (Ren & Yeo 2004, Hobday, 1998, Hobday 1999) CoPS include complex products and complex systems. The hierarchy of CoPS in Figure 5.	CoPS are defined as high cost, engineering-intensive products, systems, networks and constructs. Embedded within CoPS are high-technology product components. These product components are usually also complex systems or subsystems. CoPS's inherent complexity is due to the large number of complex product components, activities and human interactions that results in a source of project risks and uncertainty. CoPS represent major national and commercial capital asset development, and are critical to national economic and social development and well-being.		CoPSs have elaborate structures, and consists of many interconnected sub-systems and components. CoPS have a comparatively high degree of system hierarchy.	Commercial aircrafts, telecommunication networks, precision machines, nuclear power plants and intelligent buildings (such as hospitals). CoPS are typically found in aerospace and defence industries, high-tech manufacturing, chemical and petrochemical industries, pharmaceutical industries, infrastructural development of airport, seaports and mass rapid transit, electricity generation and distribution and environmental systems.
	Complex products	Complex products are considered as a network of components that, in order to function as a whole, share technical interfaces (or connections).		Aircrafts, high-speed trains, turbines, computers, aircraft engines.
	Large technical systems (LTS)	LTS, as described by Hughes (1987) under 'technological systems' above, are made up out of a number of CoPSs that functions as the command, control and communication components of LTSs. CoPSs thus shape, facilitate and in some instances constrain the development of LTSs. LTSs can be considered as one single CoPS or consists of several CoPSs.		Telecommunications network, electronic road pricing system, air travel, the internet.
	Large engineering projects (LEP)	LEP are mainly infrastructural constructs, and constitute one of the most important and significant business sectors in local and international economies. LEP may also, similar to LTS, incorporate complex products. Most LEP can be considered as a CoPS or considered to incorporate CoPS components.		Mainly infrastructure constructs: Airports, urban transport systems, oil/gas field development, power systems.
	Large IT/Software Projects	Large software projects (large enterprise information systems or embedded engineering software systems) can be single CoPS by itself, or a critical part of a larger CoPS. When compared to complex engineering systems, software development activities are largely human centered, craft-based and individualistic in		Large ERP, software systems.
Competence blocs (Eliasson & Eliasson 1997, Carlsson et al. 2002)	Competence blocs are defined as the total infrastructure required to create, select, recognise, diffuse, and exploit new ideas in clusters of firms. It is thus a set of related products and artefacts that work towards a particular function. A competence bloc thus includes a wide range of technologies and actors that are configured to stimulate the growth of an industry.		Competence blocs and technology clusters consist of parts of several technological systems supplying technological innovations applicable and related to a specific sector or industry. A competence bloc or technology cluster will include a large range of technologies.	Silicon Valley and the South German luxury car production cluster
Technology clusters (Grübler 2003)	A technology cluster is defined as a group of interconnected organisations, companies, research institutions, and other stakeholders in a particular knowledge field or industry that are liked by certain commonalities.			Silicon Valley and The Milwaukee water technology cluster.

LEVEL OF ANALYSIS

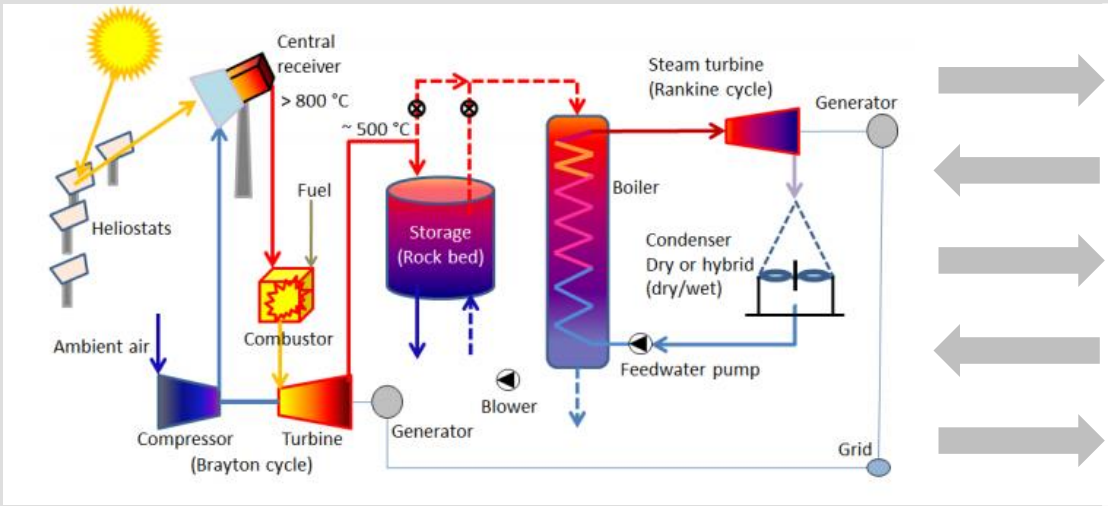






(Murmann & Frenken 2006, Pacey 1983, Brent & Musango 2011)

KEY FINDINGS



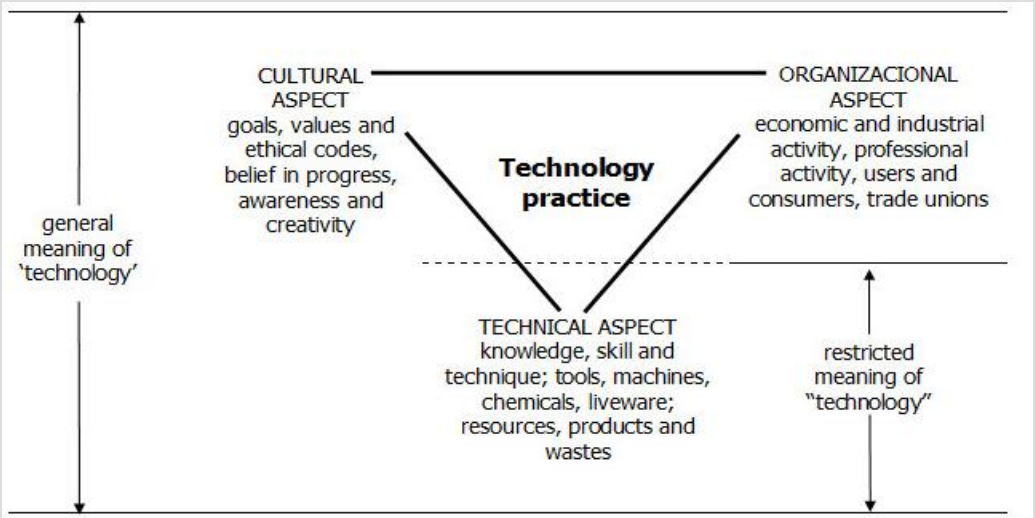
LITERATURE

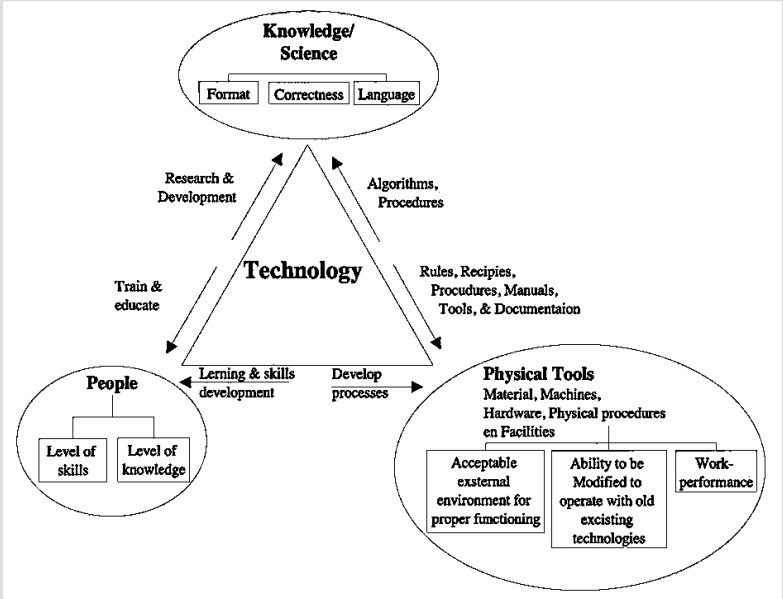
- Technology definitions
- Interaction among technology
- Technology typologies
- Level of analysis

KEY FINDINGS

TECHNOLOGY DEFINITIONS

- Difference in the delimitation and definition(s) of technology.
- **Important to differentiate between technology, and the broader system** ('technology practice' and 'technological system').
- Technology and technology practice, as defined by Pacey (1983) and De Wet (2001), provides a suitable starting point for defining nexus technology.





(Pacey 1983, De Wet 2001)

KEY FINDINGS

INTERACTION AMONG TECHNOLOGY

- Modes of interaction are considered between technologies that can be considered separate to one another.
- Whereas with a nexus technology, and given the aim of developing a conceptual model to define nexus technologies, the interaction modes between technologies, that form part of a considered whole (single nexus technology), these technologies cannot be considered in isolation
- A detailed description of technology interaction and defined relationships between technologies within a nexus technology is thus required.
- **Default mode – symbiosis (technologies are mutually dependant).**
- **Modes of interaction could possibly be contradicting – competition.**
- **Neutralism is unrealistic.**

TECHNOLOGY TYPOLOGIES

- Level of analysis differ.
- General typologies (i.e. complex technologies) are broad, and do not provide adequate detail.
- Similarities between complex product systems and nexus technology are evident, however not a ‘system of technologies’.

KEY FINDINGS

LEVEL OF ANALYSIS

- **Even though nexus technology is a 'system of technologies', it is not a 'technological system' / 'technology practice'.**
- When the **nested hierarchy** (Murmann & Freken 2006) are considered, nexus technology does not comply with the characteristics of a first order subsystem, nor with those of a system.
- Not only **differentiate between 'technology' and a 'technological system'**, but also between **technology, the concept of nexus technology, and technological systems**.

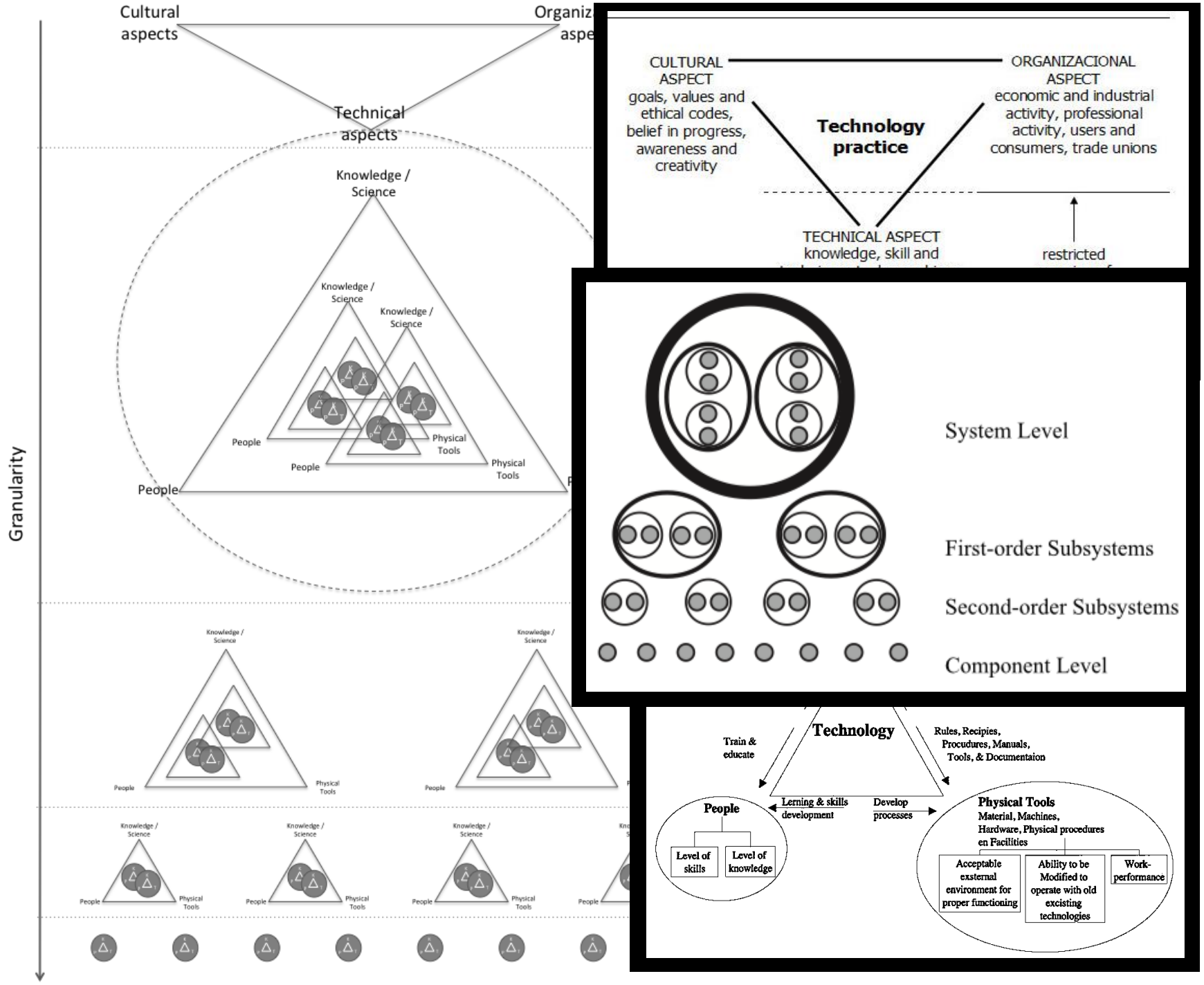
SUMMARY OF KEY FINDINGS: A number of fundamental characteristics and features of nexus technologies are not adequately captured and clearly highlighted by these bodies of literature.

CRITICAL SHORTCOMINGS: The level of analysis that nexus technology demands; at a more aggregate level than a technology, yet not a technological system. The existing definitions, typologies, levels of analysis, and modes of interaction thus **fail to address the complicatedness** in terms of these aspects of a nexus technology.

DEFINING NEXUS TECHNOLOGY

The characteristics of a nexus technology that are not adequately addressed are synthesised, and the following definition for nexus technology is proposed:

- Nexus technology is a 'system of complex technologies' that can be delineated without considering aspects other than the technical aspects of such a system. A nexus technology, even though it is in itself a system of technologies, is not a technological system;
- A mutual dependency (symbiosis) exists between technologies within a nexus technology, which will not cease to exist as long as the concerned nexus technology exists;
- The technologies (first-order subsystems) that form part of a nexus technology have distinct functions, which together contribute towards the function (common goal) of a nexus technology;
- A nexus technology has a higher order function than the functions of the technologies that form part of a nexus technology;
- The level of analysis required for a nexus technology exists between a technology – as defined by De Wet (2002), and a technological system or a technology practice (Pacey 1983; Hughes 1987), and;
- The unit of analysis of a nexus technology is the technical aspects (Pacey 1983; De Wet 2001) of a system of complex technologies.


Cultural aspects
Technical aspects
Granularity
Knowledge / Science
People
Physical Tools
CULTURAL ASPECT goals, values and ethical codes, belief in progress, awareness and creativity
Technology practice
ORGANIZACIONAL ASPECT economic and industrial activity, professional activity, users and consumers, trade unions
TECHNICAL ASPECT knowledge, skill and
restricted
System Level
First-order Subsystems
Second-order Subsystems
Component Level
Technology
Train & educate
Rules, Recipies, Procudures, Manuals, Tools, & Documentaion
Lerning & skills development
Develop processes
People
Level of skills
Level of knowledge
Physical Tools
Material, Machines, Hardware, Physical procedures en Facilities
Acceptable exsternal environment for proper functioning
Ability to be Modified to operate with old excisting technologies
Work-performance

CONCLUSION

The conceptualisation of nexus technology aims to summarises the key elements of the preceding discussion of literature and nexus technologies. Taking nexus technology as the unit of analysis, the model incorporates three key characteristics of nexus technology:

- The integrated nature of the technical aspects (technology triangles) of nexus technology;
- The level and unit of analysis at a level between technological systems and 'individual technologies' (system when nested hierarchy concept is considered), and;
- The significance of the integrated nature of the technical aspects of a nexus technology in terms of the developmental path of nexus technology – the individual technologies (first order sub-system of nexus technology) that make up a nexus technology all have individual technology s-curves, and the nexus technology's s-curve is thus a function of these s-curves.

>>> THE MANAGEMENT OF THE INTRODUCTION AND DIFFUSION OF NEXUS TECHNOLOGIES TOWARDS LARGE-SCALE FAR-REACHING SOCIO-TECHNICAL CHANGE

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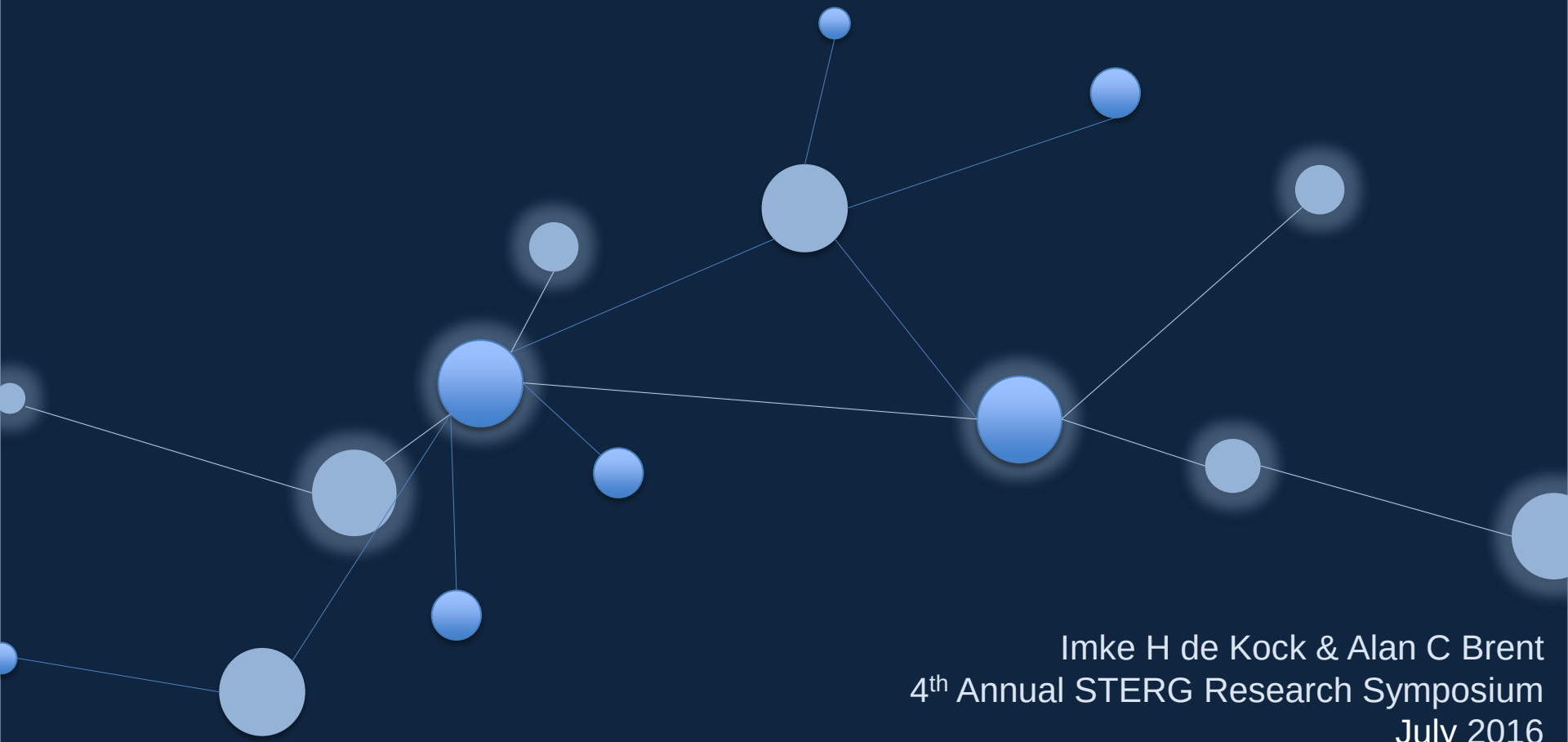

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